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TO TELECOMMUNICATIONS

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LIGHT MODULATION AND ITS
APPLICATION TO TELECOMMUNICATIONS⁽¹⁾

By Mr. Gérard MARIE⁽²⁾

The speaker recalls first the principles of light modulation and the interest it offers for the long-distance transmission of information after the appearance of the lasers. There are then indicated the main phenomena which can be brought into action to achieve it, underlining the advantages presented by the linear electro-optical effect, or Pockels effect, which appears in certain classes of crystals. Finally, the development of modulators intended for the transmission of one or more television circuits and the performances that can be expected from these systems associated to an He Ne gas laser, are described.

The report will be followed by an experiment in transmission of a television circuit by a modulated light beam, presented by Messrs. P. Billard, J. Donjon and G. Marie.

* * * * *

The following will be successively examined in the course of this report:

- the interest offered by light modulation applied to telecommunications;
- the physical phenomena that could be put into action to realize it;
- the practical development of light modulators making possible the transmission of one or more television circuits.

(1) Speech of 23 April 1964 to the Society of Civil Engineers of France.

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I - INTEREST OFFERED BY LIGHT MODULATION

Given certain information, which is represented, for example, by an electric signal as a function of time, a "carrier wave" ["onde porteuse"] which propagates itself in an environment or in space, can be used. This wave can be a sound, radio-electrical or a light oscillation. In order to transmit the information, this oscillation "will be modulated," which means that one of its parameters (its amplitude or frequency) will be changed as a function of the signal. In order to transmit a television circuit, for example, a radio-electric wave whose frequency can vary from 50 Mc to 10,000 Mc and which, in the frequency spectrum, occupied a width at least equal to the traveling band (bande passante) of the signal: approximately 10 Mc, will be used.

The use of a light wave, as a carrier, does not present a difference of principle since this also involves an electro-magnetic wave, but its frequency is very high: of the order of 10^{14} to 10^{15} cycles. This wave will generally be modulated in amplitude because, in order to detect a frequency modulation, the wave received must be thrashed [battue] with a local oscillator; this requires, for the frequencies of that order, relative frequency stabilities which are not yet achieved even with the lasers.

(1) Advantages Offered by the Use of a Light Band

These advantages are of two kinds: the light band opens to telecommunications a new frequency spectrum of very large width and for long-distance connections, it makes it possible to profit from the high directivities [directivités] which can be given to the light rays.

(a) Frequency Spectrum:

Because of the widths of the bands occupied by the connections, carrier frequencies of the order of 10,000 Mc are already used in hertzian beams. Above 30,000 Mc, corresponding to a wave length of 1 cm, the atmospheric absorption

which extends up to a wave length close to 1 while leaving a few "windows," appears.

— radio-electrical windows towards $\lambda = 8 \text{ mm}$, 4 mm and 2 mm ;

— infra-red windows towards $\lambda = 10 \mu$, 4μ and 2μ .

The use of light waves can therefore be considered as the logical sequence of the use of radio-electrical waves. The frequency spectrum they offer is extremely wide:

in the visible, for example, between $\lambda = 0.4 \mu$ and $\lambda = 0.8 \mu$ the width of that spectrum is close to $4 \cdot 10^{14} \text{ C}$, this being well above all the imaginable needs with regard to telecommunications.

(b) Directivity of the Light Waves:

For point-to-point long-distance transmission, it is important to have effective transmitters available. As a matter of fact, when a P power is transmitted in an angle cone at the top A, and the reception antenna, which is supposed to be circular, is seen from the transmitter at an angle α , the power received is equal to $P \left(\frac{\alpha}{A} \right)^2$. But the diffraction limits the directivity of a transmission antenna. If the latter is circular, of a diameter D, one still has:

$$A \leq \frac{\lambda}{D}.$$

If a parabolic mirror of diameter $D = 30 \text{ cm}$, for example, is used as an antenna, this maximum possible angle [angle limite] has a value of $\frac{\lambda}{D} = 10^{-1} \text{ rad}$ for a radio-electric wave of $\lambda = 3 \text{ cm}$ and $\frac{\lambda}{D} = 2 \cdot 10^{-6} \text{ rad}$ for a light wave of $\lambda = 0.6 \mu$, whence the advantage offered by the use of the light wave. However, this advantage is useable in practice only since the appearance of the lasers, which are high-directivity light sources. As a matter of fact, transmission angle A depends on angle α at which the diameter d source transmits; we have:

$$A = \alpha \frac{d}{D},$$

as it is possible to become aware of it, for example in figure 1, where an afocal perspective is shown, which uses two lenses of diameters d and D and focals f and F such as

$$\frac{f}{F} = \frac{d}{D};$$

at the common focus the picture of the source has a diameter

$$\delta = fa$$

whence the transmission angle:

$$A = \frac{\delta}{F} = a \frac{f}{F} = a \frac{d}{D}.$$

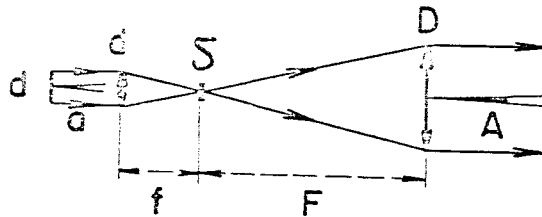


FIGURE 1

It is seen that the product " $a d$ " is a nonvariant in the optical system, which is also expressed in stating that the "extent" of the source, product of its surface s by its solid angle ψ , is a nonvariant:

$$s\psi = \left(\frac{\pi}{4} a d \right)^2 = C^*.$$

The quality of a source is then characterized by its luminance, that is, by its power transmitted per unit of surface and per unit of solid angle. It can be expressed in $\text{W.cm}^{-2}.\text{sr}^{-1}$. The table below makes it possible to compare the luminance of an He Ne gas continuous laser radiating in the red (at 0.6328μ) with the most brilliant classical lamp (luminance equal to that of the sun), which is a very high pressure mercury vapor lamp radiating a useful power close to 10 W in the visible.

Source	d (mm)	s (cm ²)	a (rd)	ω (sr)	P (W)	P/sq W.cm ⁻² .sr ⁻¹)
Laser He Ne	6	0,3	3.10^{-4}	$0,7.10^{-7}$	5.10^{-3}	$2,5.10^5$
Lamp Hg	0,3	$0,7.10^{-3}$		4π	10	10^3

The luminance of the gas laser in the visible is then 250 times higher than that of the mercury vapor lamp or that of the sun. It would similarly be calculated that it is 25,000 higher than that of a classical incandescent lamp.

(2) Disadvantages of the Use of Light:

The disadvantages of using light in telecommunications originate from the presence of the atmosphere and are tied to the mists and the atmospheric disturbance. As a matter of fact, the mists and fogs provoke a diffusion and considerable absorption of the visible light. To avoid it, it would be necessary to choose a rather large transmission wave length, for example in the 10μ atmospheric window. Unfortunately, there are no light detectors which are at the same time sensitive and rapid in that band. Besides, because of the index variations it induces, the atmospheric disturbance does not permit the use of transmission angled as small as would be possible. At sea level, it is not possible to exceed an angle of 10^{-3} to 10^{-4} radian. At the level of an observatory placed at a high altitude, this angle can be of 10^{-5} to 10^{-6} radian.

These disadvantages practically confine the use of light to space telecommunications: between satellite, rocket, and between themselves and a high altitude earth point: an observatory placed in a region in which mists are rare.

(3) Ranges That Can Be Obtained:

When it is possible to benefit from the high directivity of light, the ranges can be very big. They depend on the sensitivity of the light receiver and on the width of the band of the transmission signal.

The best detector, which can be associated to the He Ne laser radiating in the visible, is currently the photo-multiplier with the trialcaline (it contains, among other things, Cs, K and Na) or S20 photo-sensitive layer.

For a television circuit having a band width of 10 Mc and a direct amplitude modulation, it is possible to obtain a signal/noise relation equal to 40 dB when this photo-multiplier receives an average power p of $0.5 \mu W$ on the wave length of 0.6328μ , which represents $1/10,000$ of the power emitted by the laser.

Let us suppose transmission and receptions optics of the same diameter $D = 30$ cm. The transmission angle is equal to

$$A = \frac{d}{D} = \frac{0.6}{30} = 2 \cdot 10^{-2} \text{ rad.}$$

The α angle at which the sender sees the reception antenna is equal to

$$\alpha = A \sqrt{\frac{P}{p}} = A \cdot 10^{-2} = 2 \cdot 10^{-4} \text{ rad.}$$

Since this angle is equal to the quotient of the reception diameter D by the range L , the latter's value is

$$L = \frac{D}{\alpha} = \frac{0.3}{2 \cdot 10^{-4}} \text{ m} = 1.5 \cdot 10^3 \text{ m} \text{ or } 1.5 \text{ km.}$$

Much more important ranges would be obtained for transmissions of weak traveling-band signals, as could be envisaged in space telecommunications.

II - USEABLE PHYSICAL PHENOMENA

To modulate the light power emitted by a source it is possible to think first of modulating its supply. This is not possible now in a wide traveling band except with semi-conductor lasers, because the other types of lasers present time constants which are too high: for example, it is not possible to exceed a frequency modulation of some tens of Kc with the gas laser. But the semi-conductors lasers have, as of now, luminances which are weaker than those of the gas lasers; besides, they are supplied at low impedance (currents of the order of 10 A, for example), which makes difficult wide-band modulation.

These considerations show that advantage that would be derived in having available a wide-modulation traveling band light modulator, separate from the source, and whose performance would not depend on this source. In order to achieve it, it is necessary to have available on the light path a material whose optical properties (transparency, index) vary as a function of a signal applied in the form of an electric or magnetic field. It is then resorted to magnetic or electrical-optical effects. Let us set forth briefly the principle of three effects chosen among the most known or the most interesting:

- a magnetic-optical effect: Faraday effect;
- two electrical-optical effects: Kerr effect and Pockels effect.

(1) Faraday Effect

This is an effect which occurs, in a more or less intense manner, in all transparent environments. Let us consider (figure 2) a light ray originating from a source S which is polarized in a straight line by means of a polarizer P, and which crosses a transparent isotropic environment according to the propagation direction z. When this environment is subjected to a magnetic field H which is parallel to z, it is observed that the light that comes out is always polarized in a straight line, but that its polarization makes an angle θ with the initial polarization direction. Angle θ is proportional to the length l of the environment and to the applied field H:

$$\theta = k l H$$

This involves therefore a linear effect.

In order to use this effect, it is sufficient to place at the output a second polarizer P'.

When polarizer P' has the same polarization direction as P, the light amplitude which comes out is proportional to $\cos \theta$. If the light intensity at the output of the first polarizer P is called I_0 , there will be obtained at the output P' a light power:

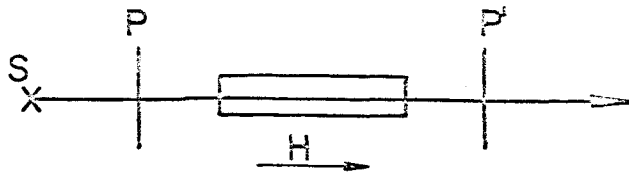


Fig: 2

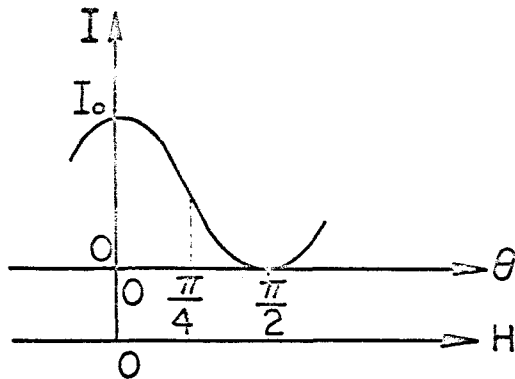


Fig: 3

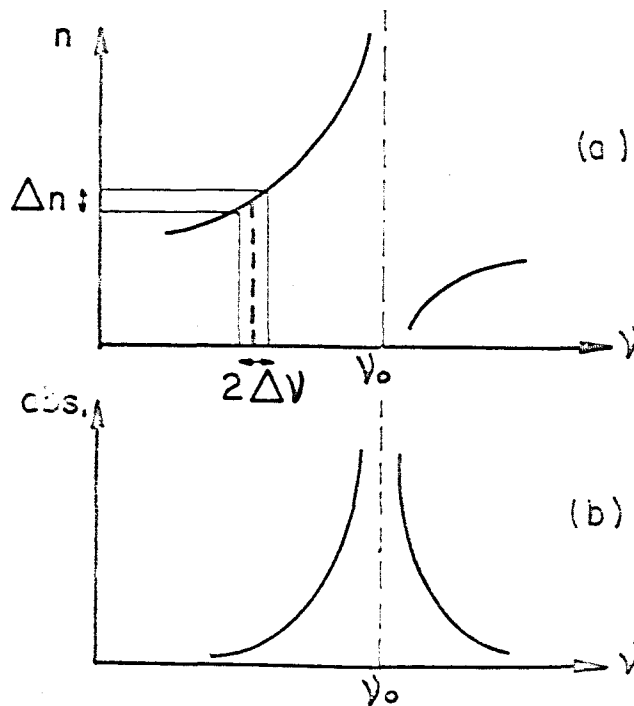


Fig: 4

$$I = I_0 \cos^2 \theta$$

$$= I_0 \cos^2 k l H.$$

The characteristic $I(\theta)$ is a sinusoid. Characteristic $I(H)$ is deduced by a simple change in the scale of the abscissas (figure 3).

In order to use this modulation in a quasi-linear area, it is sufficient to operate in the neighborhood of an inflection point of the characteristic; this can be easily obtained by a 45° rotation of the polarization direction of P' , a rotation which amounts to a change of origin of $\pi/4$ on the axis of the abscissas (fig. 3).

Brief Explanation of the Mechanism of the Faraday Effect

When a magnetic field H is applied to an environment, it is known that the electronic spins, whose original direction was not parallel to H , become animated by a precession around the direction of H , and that frequency $\Delta\nu$ of this precession is proportional to H :

$$\Delta\nu \approx 1.420^\circ \text{ c/Oersted.}$$

Everything takes place as if the incident light, having a straight line

polarization, would decompose itself into two lights having right and left circular polarizations, and frequency ν of these lights vis-a-vis the environment was decreased by $\Delta\nu$ for the component which turns in the direction of the precession and is increased by $\Delta\nu$ for the one which turns in the opposite direction.

A first consequence of this is the Zeemann effect: duplication of the transmission or absorption rays of the environment. A second consequence is the Faraday effect: if the environment is dispersive, that is, if the index of the environment varies as a function of frequency ν (figure 4 a), the environment will present two indices differing from a quantity Δn for the two circular polarization lights. Since those were in phase when electric vector \vec{E} (figure 5 a) was in the

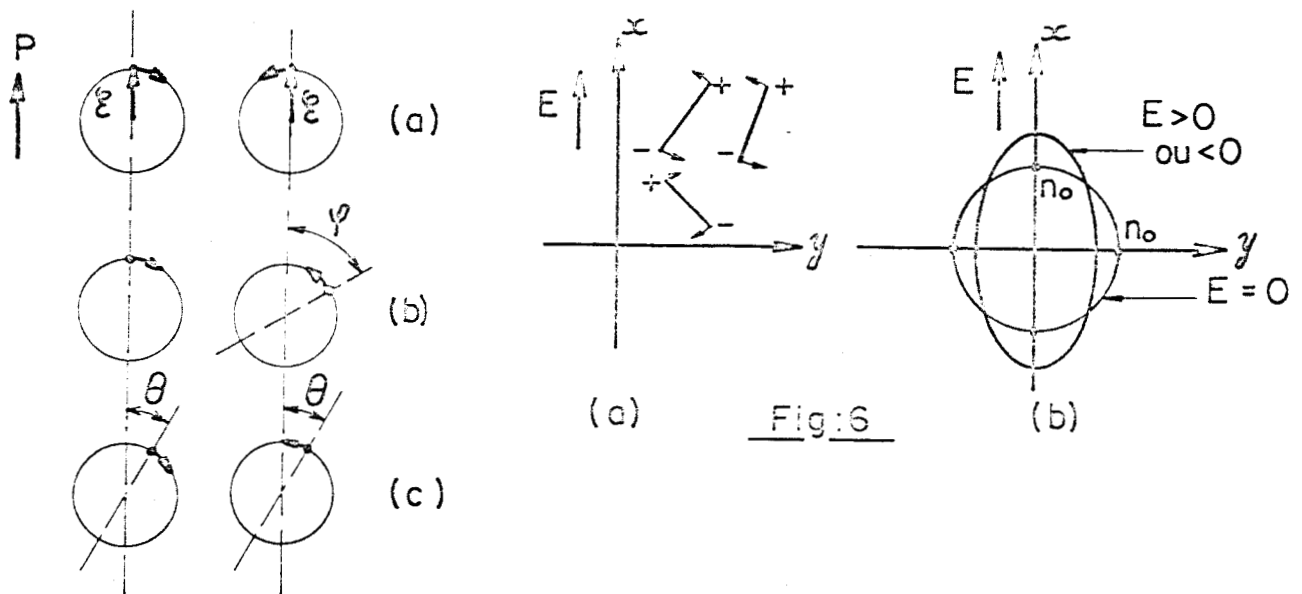


Fig:5

direction of polarizer P (taking here as the straight line polarization direction that of the electric vector, they find themselves dephased by

$$\varphi = \frac{2\pi l \Delta n}{\lambda}$$

at the output (figure 5 b) and find themselves in phase only when their electric vector makes an angle $\theta = \frac{\phi}{2}$ with P (figure 5 c). Their resultant is therefore a straight line polarization light making an angle θ with direction P.

Disadvantages of the Faraday Effect

The Faraday effect has the disadvantage of being generally of small size and of being closely tied to the absorption of the environment.

One of the transparent materials which is most sensitive to the Faraday effect: zinc sulphide ZnS, for example, gives for the visible radiations a rotation θ of only 0.3 minute of angle per gauss and per cm. Since it is already difficult to obtain alternating fields of the order of the gauss in a wide traveling modulation band, such an effect is much too weak.

Since the effect is tied to the dispersion of the material, it is possible to seek to place oneself in an area in which the index varies rapidly with the frequency, that is, close to an absorption ray. As a matter of fact, close to such a ray, of ν_0 frequency, the index and the absorption vary as shown in figure 4 (besides, these operations have the same rhythm as the variation of the imaginary and real parts of the impedance of a resonant circuit). The Faraday effect will therefore be more intense close to ν_0 , but, since the absorption itself also rises rapidly close to this frequency, it will no longer be possible to use a long path in the material; this limits the rotation θ which is obtained.

The Faraday effect becomes of a useable magnitude in modulation only when it is associated with magnetic properties of the transparent environment. This is what takes place, for example, with the Yttrium garnet, a magnetic material which is transparent only in infra-red.

(2) Kerr Effect

What is called the Kerr effect is the appearance of a birefringence [double refraction] in an isotropic environment when there is applied to it an electric

field of a direction orthogonal to the propagation direction of light. The material which presents the most pronounced Kerr effect is a liquid: nitrobenzene ($C_6H_5NO_2$).

Let us examine the mechanism of this effect: the nitrobenzene molecules are molecules of elongated form which, under the action of an electric field, acquire an electric polarization which is more especially induced in the direction of the axes of the molecule. When these molecules are not parallel to direction x of applied electric field E , a cell (figure 6 a) appears which tends to bring closer the direction of the axis of the molecules to direction x (this mechanism is analogous to that which, in magnetism, tends to orient iron filings in the direction of the field lines).

In the $x y$ plane which is normal to the propagation direction of light, a more dense environment is obtained in direction x than in direction y , and vis-a-vis the light, this environment presents a bigger index when the electric vector \vec{E} of the light wave is parallel to x than when it is parallel to y .

It is possible to show (figure 6 b) the variation of the index as a function of the direction of vibration \vec{E} in the $x y$ plane by a circle in the absence of continuous electric field E and by an ellipse in the presence of that field. The index variation between x and direction y does not depend on the direction of field E . Therefore, one is dealing with a quadratic effect: close to the 4th order, index variation Δn is proportional to E^2 . In order to use this effect, it is sufficient, for example, to place the chamber [cuve] containing the nitrobenzene between the two polarizers P and P' crossed and oriented according to the bisectors of axes $x y$. Then it is necessary to split the polarized incident light in the direction P (figure 7) into two components of polarization directions parallel to x and to y , which are propagated at different speeds in the nitrobenzene. After a path l these two components are dephased by an angle:

$$\varphi = \frac{2\pi l \Delta n}{\lambda}$$

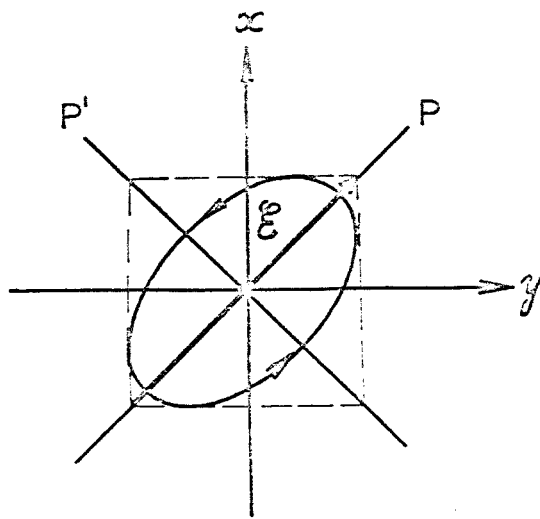


Fig:7

and their resultant is generally an elliptical vibration inscribed in the square having as diagonal the incident straight-line vibration.

It is easily computed that the axes of the elliptical vibration, which are parallel to directions P and P' (figure 7) are respectively proportional to $\cos \frac{\varphi}{2}$ and $\sin \frac{\varphi}{2}$. At the outlet of the second polarizer P' the light intensity therefore takes the value

$$I = I_0 \sin^2 \frac{\varphi}{2} \\ = I_0 \sin^2 k E^2 l.$$

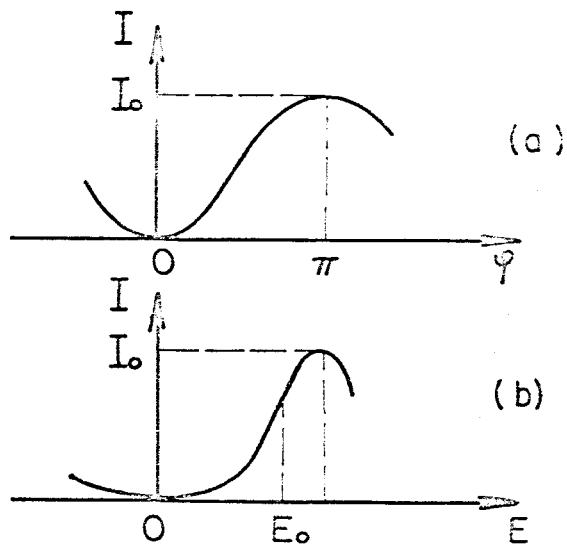


Fig: 8

Characteristic $I(\varphi)$ is a sinusoid (figure 8 a) and characteristic $I(E)$ takes the rhythm indicated in figure 8 b (as a function of the 4th degree in the neighborhood of $E = 0$).

In order to obtain a quasi-linear modulation, it is sufficient to operate in the neighborhood of an inflection point of the characteristic, which can be obtained only by superimposing a continuous electric field E_0 (figure 8 b) on the alternative modulation field.

Disadvantages of the Kerr Effect:

- (a) Although comparatively much more sensitive than the Faraday effect, the Kerr effect makes necessary nevertheless high modulation fields. For example, in the nitrobenzene a field in the neighborhood of 20 kV/cm is necessary to obtain a dephasing ϕ equal to π over a distance of a few centimeters.
- (b) The quadratic character of the characteristic accentuates more this lack of sensitivity for the weak fields and imposes the use of a continuous field to obtain a quasi-linear modulation.
- (c) The inertia of the rotation of the molecules introduces a time constant of the order of 10^{-10} to 10^{-11} second; this imposes a theoretical maximum modulation frequency of the order of 10^9 to 10^{10} cycles.
- (d) The dielectric losses of the nitrobenzene are very important. The operation with a continuous field E_0 already makes necessary an elaborate purification. In high frequency it is not practically possible to envisage a continuous operation well before the maximum frequency introduced by the inertia of the molecules.

Use of the Kerr Effect

Because of its properties the Kerr effect is used practically only in impulsional regime, particularly for the realization of rapid obturators. It has thus made possible the realization of photographic obturators whose duration of opening can be of the order of 10^{-8} to 10^{-9} seconds.

(3) Pockels Effect

This is a linear electrical-optical effect which starts the shifting of ions in a crystalline network and which can appear only in crystals deprived of a symmetry center. In order to give an idea of the mechanism of this effect, let us briefly describe the action of an electric field in a cubic crystal such as zinc sulphide.

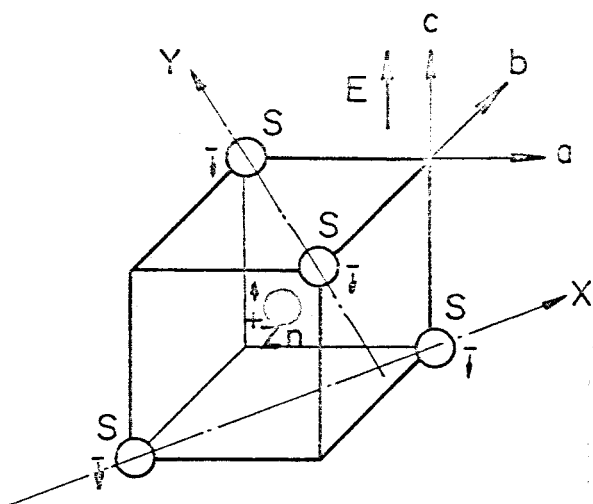


Fig: 9

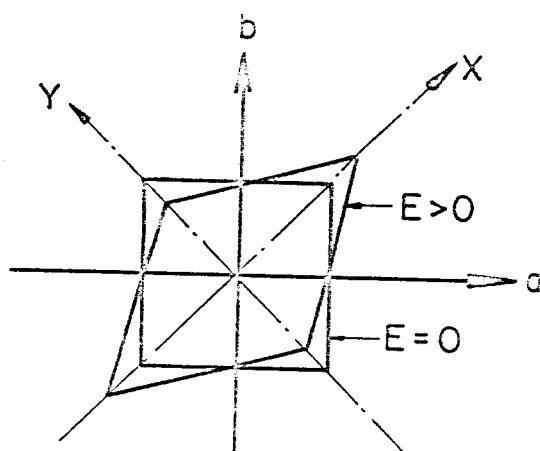


Fig: 10

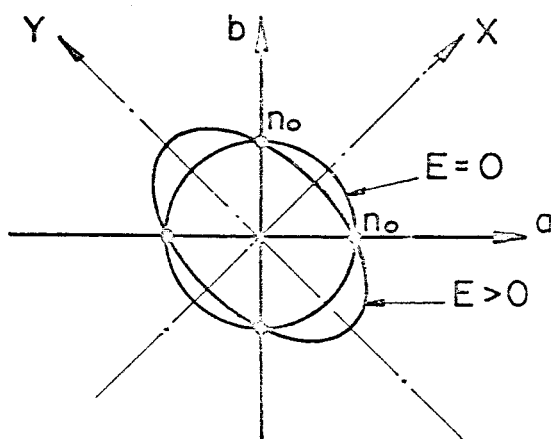


Fig: 11

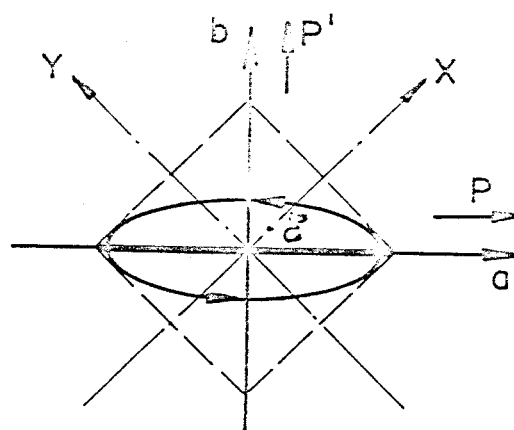


Fig: 12

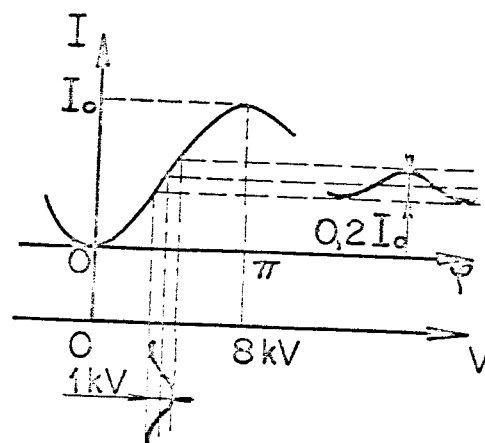


Fig: 13

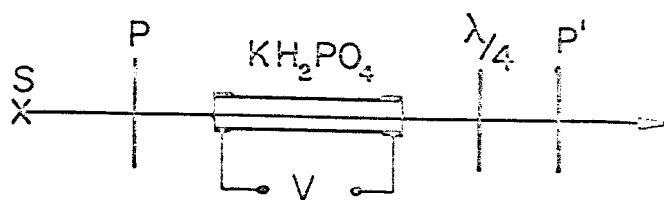


Fig: 14

The ZnS crystal belongs to class $\bar{4} 3$ of the cubic system, a class which presents only half the symmetry elements of the cube and which, especially, does not present a symmetry center.

The fundamental "motif" of this crystal, which represents 1/8 of the complete link, is constituted by 4 S ions at the tops of a tetrahedron whose center is occupied by a Zn ion (or inversely 4 Zn ions surrounding one S ion). These tetrahedrons always have the same orientation in the crystal, which means, for example, that the closest Zn ions are always above the S ions which are aligned according to the first diagonal X of the crystallographic axes a and b (supposed to be horizontal), and always below the S ions aligned according to the second diagonal Y (figure 9).

The Zn and S ions have opposite charges. Under the influence of an electric field E directed parallel to crystallographic axis c, the centers of gravity of these charges move: that of X + + upward and that of S - - downward, for example. The electrical-static attraction between Zn + + and S - - ions therefore tends to decrease for the Zn and S aligned parallel to diagonal X and to increase for the Zn and S ions aligned parallel to Y, a phenomenon which has two consequences:

- the appearance of a mechanical distortion: it is the piezoelectric effect (a square becomes a lozenge, figure 10).
- the appearance of a birefringence [double refraction]: it is the Pockels effect (the index in the plane a b is no longer represented by a circle, but by an ellipse of axes X and Y, figure 11).

These two effects are linear: the sign change of field E reverses the direction of the mechanical distortion and the birefringence (permutation of the roles played by diagonals X and Y). The presence of a symmetry center—for example, if Zn was surrounded by 8 S at the tops of a cube (case of the Cs Cl crystal)—would make the directions of bisectors X and Y play the same role, and

it would no longer be possible to have a linear effect, hence no more piezoelectric effect or Pockels effect.

It is possible to put in action the birefringence induced by the Pockels effect in the same way as that induced by the Kerr effect was put in action. If the incident light is polarized by means of a polarizer P of a direction parallel to axis a, this light splits into two components parallel to X and Y which see environments whose index differs by a quantity Δn proportional to E.

After path I these components are dephased by

$$\varphi = \frac{2\pi l \Delta n}{\lambda}$$

and their resultant is an elliptical polarization light inscribed in a square having as diagonal the incident vibration (figure 12). When a second polarizer P' of a polarization direction perpendicular to that of P is placed at the output, the amplitude of light variation, at the output, is proportional to $\sin \frac{\varphi}{2}$, and its intensity is given by

$$\begin{aligned} I &= I_0 \sin^2 \frac{\varphi}{2} \\ &= I_0 \sin^2 k E l \\ &= I_0 \sin^2 k V \end{aligned}$$

calling V the difference of potential which makes it possible to apply, in direction c, field E. The characteristics I (φ) and I (V) are then sinusoids which are deduced one from the other by a simple change of the scale of the abscissae (figure 13).

The voltage V (equal to the product E-l), which makes it possible to obtain a dephasing $\varphi = \pi$, does not depend on the length of the crystal. For the visible, it is in the neighborhood of 12 kV for the Zn S crystal and of 8 kV for the crystal of the quadratic system: monopotassic phosphate (KH_2PO_4), which is more common than Zn S.

In order to obtain a quasi-linear light modulation, it suffices to operate in the neighborhood of an inflection point of the characteristic $I(V)$ (figure 13) by superimposing on the modulation voltage a continuous voltage of 4 kV (in case KH_2PO_4 is used) or, like the linear effect, by introducing a constant dephasing $\varphi_0 = \frac{\pi}{2}$ by means of a fourth of a wave dephasing blade placed, like the crystal, between two polarizers (figure 14).

Advantages over the Other Effects Presented by the Pockels Effect

(a) The Pockels effect is the most sensitive of those we have just described. The use of quadratic crystals (of the KH_2PO_4 type) which possess an optical axis, practically imposes having the light propagate along that axis, which is also the axis in the direction of which the field is applied. The dephasing obtained then depends only on voltage V applied, and not on the length of the crystal. On the other hand, the use of cubic crystals (or the ZnS or CuCl type) would make possible a propagation of the light in a direction (X , for example) normal to that of the field.

The necessary modulation voltage would then be reduced in the relation of the length to the thickness of the crystal. Unfortunately, the cubic crystals which are sensitive to the Pockels effect are rare, and their manufacture at the present time is still very arduous.

(b) The effect is linear; this gives it, for the small signals, a better response than that of the Kerr effect. Besides, the linearity of characteristic $\varphi(V)$ makes it possible to envisage linear combinations such as the addition of the dephasings of a fourth of a wave plate [lame] and a Pockels crystal, or dephasings of several Pockels crystals (see paragraph III).

(c) The time constant of the Pockels effect, which is connected to the inertia of the movement of the ions in a crystal, is situated between that of the Faraday effect (electronic spins) and that of the Kerr effect (rotations of molecules).

Its magnitude can be given by the vibration resonance frequency of the ions. This frequency, which is the field of infra-red radiations, is of the order of 10^{13} C ($\lambda \approx 30 \mu$) for Zn S and of the order of 10^{14} C ($\lambda \approx 3 \mu$) for KH_2PO_4 where the effect is essentially connected with the movement of the ions H.

(d) The dielectric losses of the crystals which are sensitive to the Pockels effect are generally negligible up to modulation frequencies of the order of 100 Mc. In the KH_2PO_4 crystal, for example, the losses become important starting with 1000 Mc and limit the practical use in continuous regime to a frequency of the order of 3000 Mc.

III - DEVELOPMENT OF POCKELS EFFECT LIGHT MODULATORS

These modulators were developed at the Laboratories for Electronics and Applied Physics in collaboration with Mr. J. Donjon. Moreover, they represent a part of the results of work of Mr. Donjon toward a 3rd cycle Doctorate thesis.

We will describe here only two types of modulators of traveling bands of 10 Mc and 100 Mc respectively.

(1) 0-10 Mc Video Modulator

To realize a video modulator capable of modulating directly the intensity of the light proportionately to a television signal of 10 Mc of traveling band, it suffices to use a KH_2PO_4 crystal placed, with a quarter of a wave plate [lame] between two crossed polarizers (figure 14) and to subject it to an electric field proportional to the television signal.

This field can be applied by means of two transparent conductor layers deposited on the faces of the crystal or, more simply, by means of two transparent conductor rings placed at the tips, when the crystal is in elongated form. The Television signal is applied to an amplifier whose final stage comprises a double tetrode in push pull class B capable of delivering in a 10 Mc band, a signal peak of 1 kV on an impedance of 2500Ω (output power for a sinusoidal signal: 50 W).

It can be easily seen, according to the characteristic of figure 13, that such a signal makes it possible to obtain a modulation rate of the light close to 20 percent. In order to increase this rate we have used three crystals placed in series on the light path and electrically attacked in parallel. Figure 15 a shows the method of realization which was adopted: the three crystals (diameter 6 mm and length 22 mm) are glued to each other and the extreme faces are protected from the humidity of the air by two glass plates.

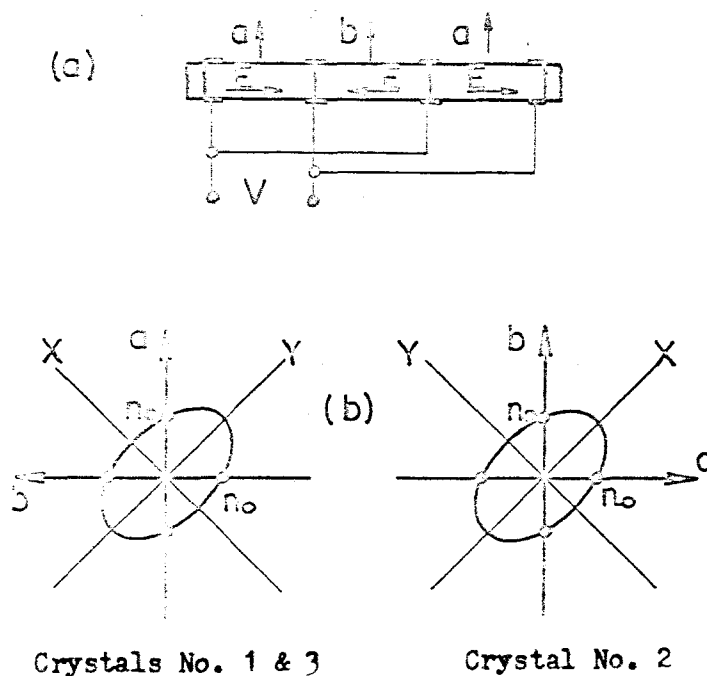


Fig. 15

In such a system, the fields applied to the three crystals have alternate directions and, in order to obtain an additive effect, it is necessary also to alternate the orientation of axes a and b of the crystals (figure 15 a).

If a positive electric field is assumed, in the extreme crystals, for example, it is seen (figure 15 b) that the index ellipse then presents its big axis in the direction of bisector Y for these crystals and in direction X for the crystal placed in the center. As a result of the rotation of axes a and b from one crystal

to the next the index ellipse, therefore, presents the same orientation in space for the three crystals, and the dephasings are added. Thus a modulation rate close to 60 percent is obtained.

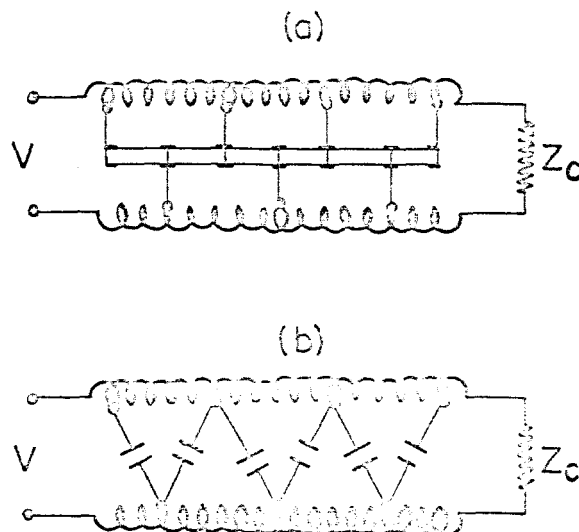


Fig: 16

This modulator has been used, at the end of the report, for the transmission of a television image over a distance of 10 m with a simple incandescent lamp as source of light. The opening diameters of the transmitters and receiver were 0.5 cm and 5 cm respectively. For a receiving opening of 2 cm, the relation signal/noise obtained was of the order of 30 dB, which is in sufficiently good accordance with the sensitivity and range calculations of paragraph I.

REMARK:

The KH_2PO_4 crystals present an important piezoelectric effect. Besides, it is the use of this effect which led to the perfecting of their large-scale manufacturing some twenty years ago.

In a traveling band which covers 0 to 10 Mc, there always exists a resonance frequency of the crystal (frequency close to 200 Kc for the crystals of a diameter of 6 mm).

Very important resonances in the spectrum transmitted would result if the precaution were not taken to muffle mechanically the crystal by means of a material capable of preventing it from vibrating or from absorbing its vibrations; this made it possible to reduce a 200 Kc resonance to an acceptable level.

(2) Wide-Band Modulator: 1-100 Mc

The alternation principle of the crystals makes it possible to envisage multiplying their number and realizing a distributed modulator.

Figure 16 shows its principle: a certain number of crystals are assembled, as in the previous modulator, by alternating the respective directions of their axes a and b. The contact rings, which are placed at the tips of the crystals, are alternatively connected with two distributed inductance coils of the same length as the crystals as a whole; they form with the latter a delay line whose electric diagram is shown in figure 16 b. The diagram shows that what is involved is a classical line made up of cells of γ whose orientation has been alternated.

The practical realization of this modulator comprises 6 crystals measuring 5 x 5 x 15 mm. The line is adapted to its characteristic impedance at 800Ω . The modulator is attacked [attaqué] by a distributed amplifier capable of delivering a maximum peak to peak signal of 250 V on the 800Ω impedance (maximum output power for a sinusoidal signal: 10 W).

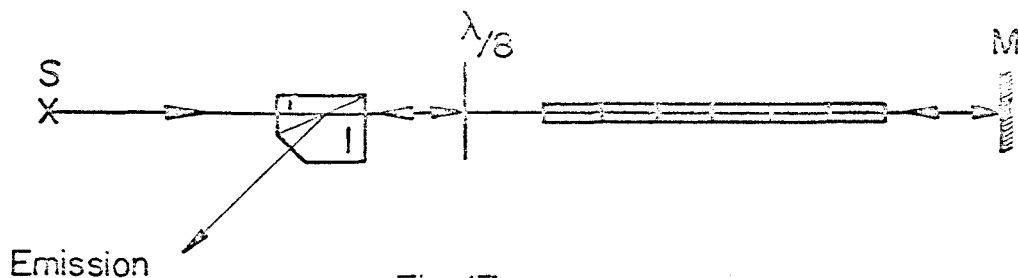


Fig:17

The traveling band covers 1 to 100 Mc, a limit which corresponds approximately to the traveling band of the present rapid photomultipliers.

A peak to peak voltage of 250 V makes it possible to obtain with 6 crystals a modulation rate (towards $\lambda = 0.6 \mu$) of the order of 25 percent if account is taken of the field loss due to the relatively short length of the crystals in relation to the size of the rings. Since the propagation time of the light in the crystals is negligible in the serviceable traveling band, it is possible to obtain a modulation rate of 50 percent by a double path of a light ray.

Figure 17 indicates its principle: a simple total reflection polarizer (Glazebrouk prism, for example) replaces the two crossed input and output polarizers (figure 14): at the input this polarizer lets pass towards the crystals only the light whose electric vector is in the plane of the figure; after reflection on a mirror M the light goes through the crystals a second time and its component, whose electric vector is normal to the plane of the figure, is reflected by the prism towards the transmission optics. In such a device, it is advisable that the twice-crossed dephasing plate not be more than $\lambda/8$ plate (dephasing $\varphi = \pi/4$).

This type of modulator can serve for large capacity transmissions: ten television circuits, for example. It is also possible to use it for the transmission of a single circuit by using a binary coding system (modulation in Δ , for example) which, at the cost of a widening of the traveling band (50 to 100 Mc), makes it possible to be contented at the reception with a signal/noise relation much weaker, and thus makes it possible to obtain a larger range than with the first modulator.

REMARKS:

— Since the chosen traveling band starts at only 1 Mc, the piezoelectric is no longer to be feared and the mechanical muffling of the crystal is no longer necessary.

— The presence of an optical axis in the KH_2PO_4 type crystals makes necessary a great precision of their alignment parallel to the axis.

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The writer wants to thank the Directorate of the Laboratories of Electronics and Applied Physics, which has authorized the publication of this article.

The discussion which concluded this conference can be found on the next pages.

DISCUSSION

PRESIDENT BOUTRY - I thank Mr. Marie and his collaborators for the presentation of this brilliant experiment. Before going any further, are there any questions which a member of the audience would want to ask Mr. Marie?

A LISTENER - Have you performed experiments with progressive-wave photodetector tubes?

MR. MARIE - We have not performed any experiments with this type of photodetectors. These tubes comprise a photo-sensitive layer followed by a propeller collector. They do not present a multiplication of electrons and, therefore, no current amplification. The progressive-wave propeller accordingly serves only as a collector device of a rather high impedance and of a very wide band.

We have performed, however, experiments of light modulation towards 100 Mc by using, at the reception, another process: the frequency change inside a photomultiplier.⁽¹⁾

A LISTENER - I would like to know if the laser can be used for reception or if this is theoretically impossible.

MR. MARIE - I believe that the difficulties encountered in the use of a laser for reception, in order to make a photo-mixing, are essentially caused by the instability of the frequency of the laser. In order to obtain a beat frequency of the order of the Mc with reception frequencies close to $5 \cdot 10^{14}$, it is necessary to stabilize the latter nearly at better than 10^{-10} . This presently appears possible only when the two lasers are side by side and present close characteristics. When two lasers, which are far apart, are involved, this precision seems to be still unattainable at the present time.

(1) G. Marie and J. Nussli: "Reception of Modulated Light at a Frequency of 900 MHz by Means of a Photomultiplier Comprising a Frequency Changer Stage," CR. Académie des Sciences, Paris, volume 258, p.p. 5179-5182 (25 May 1964).

A LISTENER - Is that a deflection/dérive/ of the simulated transmission frequency?

MR. MARIE - What are simply involved are thermic deflections due to the dilatation of the cavity of the laser. The latter generally oscillates on several wave lengths which depend on the distance of the mirrors (sub-multiple wave lengths of double this distance in the case of axial processes [modes/]). When the laser is quite short, it can oscillate on only a single wave. In any case, the slightest thermic dilatation, which changes the distance of the mirrors, leads to a displacement of the oscillation frequency which is much too large to make possible the reception by photo-mixing (frequency displacement above 10^8 cycles per degree, for example).

Besides, the laser used in reception can introduce a noise due to the amplitude fluctuations of its different processes [modes/]. I think, however, that the main difficulty of use is caused by the instability of the frequency.

A LISTENER - Would you obtain better results with a monochromatic light?

MR. MARIE - Since we are using an amplitude modulation of the light and detectors which are sensitive to the light intensity received, there is no difference in principle in using an incoherent light or a monochromatic coherent light. The use of the latter makes possible, however, the use of a narrow-band filter at the reception; this decreases the level of parasitic light received and, therefore, the noise it generates. The transmission ray of a laser is extremely thin and, although one is unable to make a filter which is that narrow, the weakening of the parasitic light obtained by the use of a filter is already very important.

PRESIDENT BOUTRY - If no one else wants to speak, I believe I will be your faithful interpreter in thanking Mr. Marie for having kindly accepted to discuss for us, in a brilliant manner, a particularly new topic to which he brought a personal contribution of value. I, therefore, thank him and his associates on your behalf.